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# RESEARCH MEMORANDUM

## INVESTIGATION OF CARBON DEPOSITION IN AN I-16 JET-PROPULSION ENGINE AT STATIC SEA-LEVEL CONDITIONS


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and Edward G. Stricker

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# INVESTIGATION OF CARBON DEPOSITION IN AN I-16 JET-PROPULSION ENGINE AT STATIC SEA-LEVEL CONDITIONS

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## SUMMARY

In order to study the effect of fuel properties on carbon deposition in jet-propulsion-engine combustors, an investigation was conducted with seven fuels - kerosene, Diesel fuel oil, toluene, xylene, 62-octane gasoline, a commercial solvent, and AN-F-32 (JP-1) - in an I-16 engine at static sea-level conditions and a constant rotor speed. Data are presented comparing the total carbon deposited by each fuel and curves are presented showing the distribution of carbon deposits among the 10 chambers of the unit. Additional data show the reproducibility of results and the effect of a reduction in exhaust-jet-nozzle area on the carbon-forming tendency of kerosene.

With the exception of Diesel fuel oil, carbon deposition increased with increasing aromatic content of the fuel. A Diesel fuel oil, with an aromatic content of 19 percent, produced carbon deposits exceeding those resulting from the two 100-percent-aromatic fuels (toluene and xylene). No definite relation between carbon deposition and volatility was established in this investigation.

## INTRODUCTION

An investigation to determine the effects of fuel properties on the performance of jet-propulsion engines is being conducted at the NACA Cleveland laboratory. The general objective of this work is to provide data that may be used as a basis for determining jet-propulsion-fuel specifications.

A preliminary investigation planned to ascertain specifically the carbon-deposition tendencies was made of seven fuels having widely different properties. Several runs at the same conditions were made with two fuels in order to determine the reproducibility of the test results. The investigation was made in an I-16 jet-propulsion engine, which was used for the investigation reported in reference 1. The engine was operated at static sea-level conditions corresponding approximately to normal take-off for the I-16 engine.

## EQUIPMENT AND FUELS

A detailed description of the test equipment and drawings of the I-16 jet-propulsion engine are presented in reference 1. All of the runs were made with an exhaust-jet nozzle having a cross section of approximately 120 square inches except one run in which a nozzle having a cross section of 114 square inches was used. The standard fuel-injection nozzles for the engine (21.5 gal/hr, 80° spray angle) were used in the investigation.

The physical properties and chemical composition of the test fuels - kerosene, Diesel fuel oil, toluene, xylene, 62-octane gasoline, a commercial solvent designated solvent 1, and AN-F-32 (JP-1) - are listed in table I. The commercial solvent used in this investigation was part of the same batch (solvent 1) used for the study reported in reference 1. The particular fuels used were selected to determine the effects of volatility and composition on carbon deposition. The over-all boiling range represented by the fuels is approximately 110° to 680° F.

## PROCEDURE

Tests were made at conditions approximating zero ram at sea level for the I-16 jet-propulsion engine. For each fuel the rotor speed was held approximately constant at 16,000 rpm (indicated) for 2 hours.

The carbon deposited on the combustion-chamber liners was determined by weighing the liners before and after each run. Carbon deposits were removed by immersing the liners in a bath containing 6 N (approximately) hydrochloric acid maintained at a temperature of 150° F. From 6 to 9 hours were required to remove all carbon (and oxides) and to leave a clean surface. After this treatment the surface of the liners had an etched appearance distinctly different from that of new liners; consequently, before use new liners were treated in the acid bath to obtain an etched surface.

[redacted]

## DISCUSSION OF RESULTS

Reproducibility of data. - Results of four runs with kerosene and two runs with Diesel fuel oil at substantially the same conditions are presented in figure 1. Although the reproducibility of carbon deposits in the individual combustion-chamber liners was very poor, the total weight of carbon deposited in all liners of the engine was remarkably consistent. For the four kerosene runs (fig. 1(a)), the range of total carbon deposited was approximately 105 to 119 grams; for the runs with Diesel fuel oil (fig. 1(b)), the total carbon deposited was 356 and 379 grams. The average tail-pipe temperature observed in these tests was 1090° F.

In general, the larger quantities of carbon were found in liners 5, 6, and 7, which are at the bottom of the engine; however, in the runs with Diesel fuel oil (fig. 1(b)) relatively heavy deposits also occurred in liner 4 (run 12) and liners 1, 2, and 9 (run 9).

Reduced exhaust-jet-nozzle area. - One kerosene carbon-deposition run was conducted with an exhaust-jet nozzle having a cross-sectional area of about 114 square inches (fig. 2). The quantity of carbon obtained was 260 grams, or more than twice the amount found in the runs with the 120-square-inch exhaust nozzle (fig. 1(a)). Higher burner operating temperatures, indicated by an increase of 140° F in the tail-pipe temperature, may have caused the excessive carbon deposition.

Fuel comparison. - The distribution of carbon deposits among the individual combustion-chamber liners for each of the seven fuels is presented in figure 3. The total carbon deposit for each fuel is also indicated. The trend of heavy carbon deposition in the lower liners, which was found when kerosene was used, cannot be generally anticipated. Some of the liners warped excessively in the runs with the two aromatic fuels, xylene and toluene. This warping did not, in general, accompany heavy carbon deposition.

The relation of the total carbon deposit to the volatility and the aromatic content of each fuel is shown in figures 4(a) and 4(b), respectively. From a comparison of these figures, the aromatic content of the fuel (except that of Diesel fuel oil) appears to have the greater effect in inducing the formation of carbon. Diesel fuel oil, with a relatively low aromatic content and a high final boiling point of approximately 680° F, produced carbon deposits exceeding those resulting from 100-percent aromatic fuels.

A photograph of combustion-chamber liner 7 after a 2-hour run (run 12) with Diesel fuel oil is presented in figure 5. About half of the cross-sectional area of the liner is blocked by the excessive carbon formation.

## SUMMARY OF RESULTS

An investigation of carbon deposition conducted in an I-16 jet-propulsion engine at static sea-level conditions indicated that:

1. With the exception of Diesel fuel oil, carbon deposition increased with increasing aromatic content of the fuel. A Diesel fuel oil with an aromatic content of 19 percent produced carbon deposits exceeding those resulting from 100-percent aromatic fuels.

2. No definite relation between carbon deposition and volatility was established.

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## REFERENCE

1. Bolz, Ray E., and Meigs, John B.: Fuel Tests on an I-16 Jet-Propulsion Engine at Static Sea-Level Conditions. NACA RM No. E7B01, 1947.

TABLE I - PHYSICAL DATA AND APPROXIMATE COMPOSITION

OF FUELS TESTED IN I-16 ENGINE

| Fuel | Boiling range (°F) | Specific gravity | Hydrogen-carbon ratio | Lower heating value (Btu/lb) | Approximate composition (percent by volume) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Paraffin | Naphthene | Aromatic[1] | Olefin |
| Kerosene | 338-529 | 0.805 | 0.176 | 18,500 | 34 | 51 | 14 | 1 |
| Diesel fuel oil | 384-680 | .838 | .154 | 18,400 | | | 19 | 2 |
| Toluene | 224-228 | .871 | .096 | 17,500 | | | 100 | |
| Xylene | 273-278 | .867 | .106 | 17,600 | | | 100 | |
| 62-octane gasoline | 110-224 | .702 | .182 | 19,000 | 76 | 22 | 2 | Low |
| Solvent 1 | 307-382 | .769 | .174 | 18,800 | 61 | 38 | 1 | Low |
| AN-F-32 (JP-1) | 320-453 | .792 | .150 | 18,500 | | | 12 | 1 |

[1]Aromatic analyses obtained by A.S.T.M. method ES 45a.

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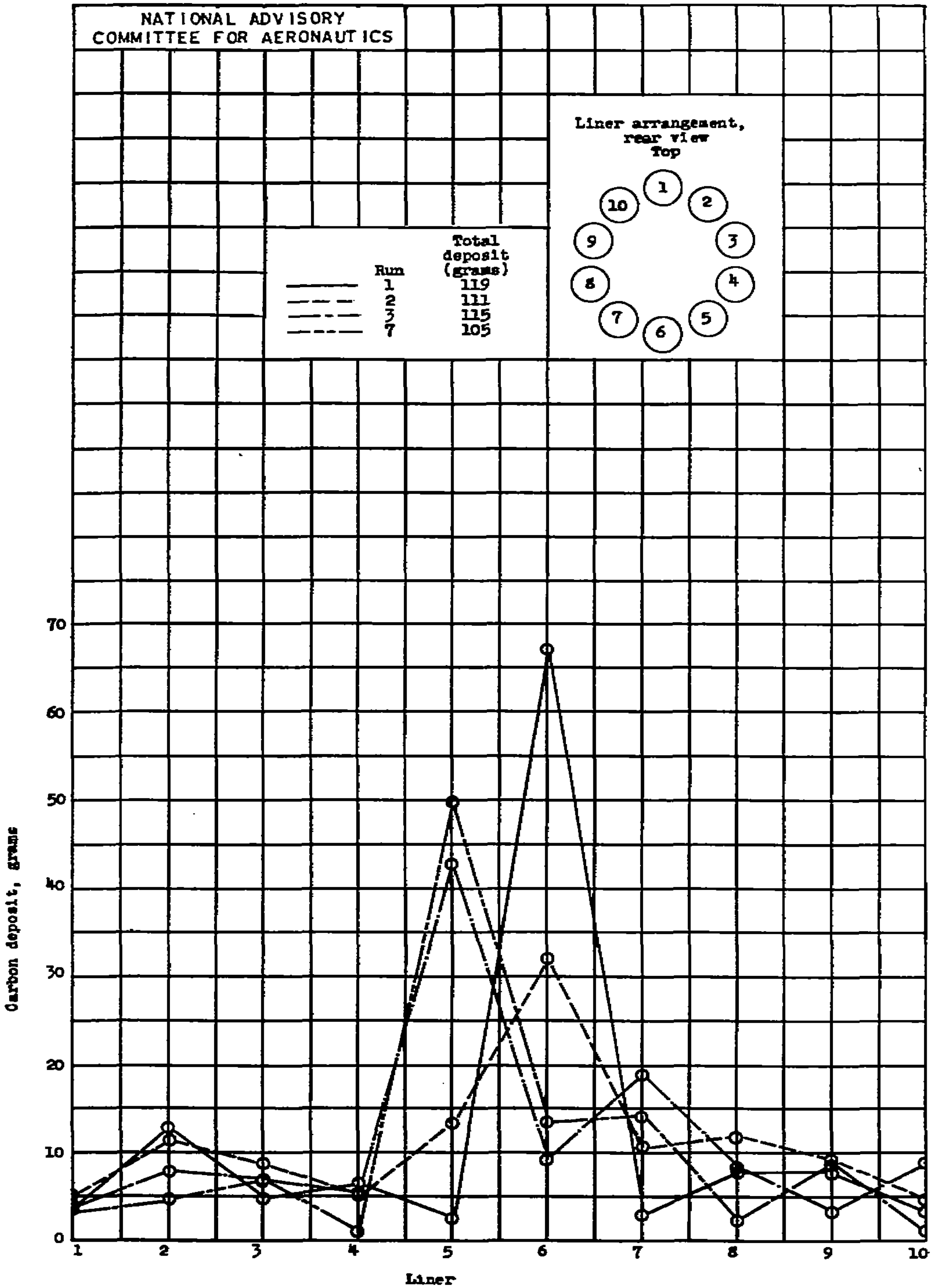
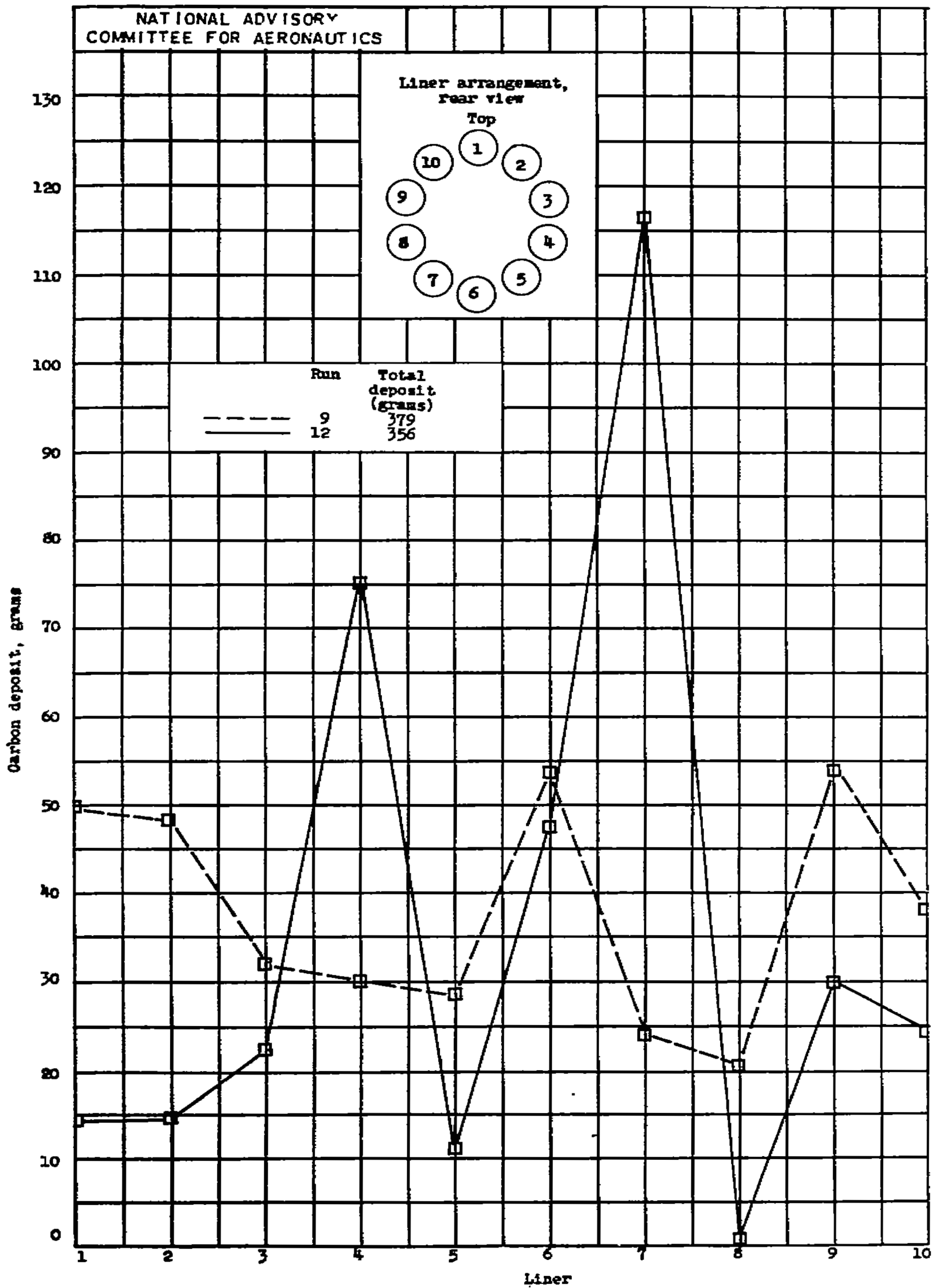



(a) Kerosene.

Figure 1.- Reproducibility of carbon-deposition data obtained in I-16 engine.




(b) Diesel fuel oil.

Figure 1. - Concluded. Reproducibility of carbon-deposition data obtained in X-16 engine.

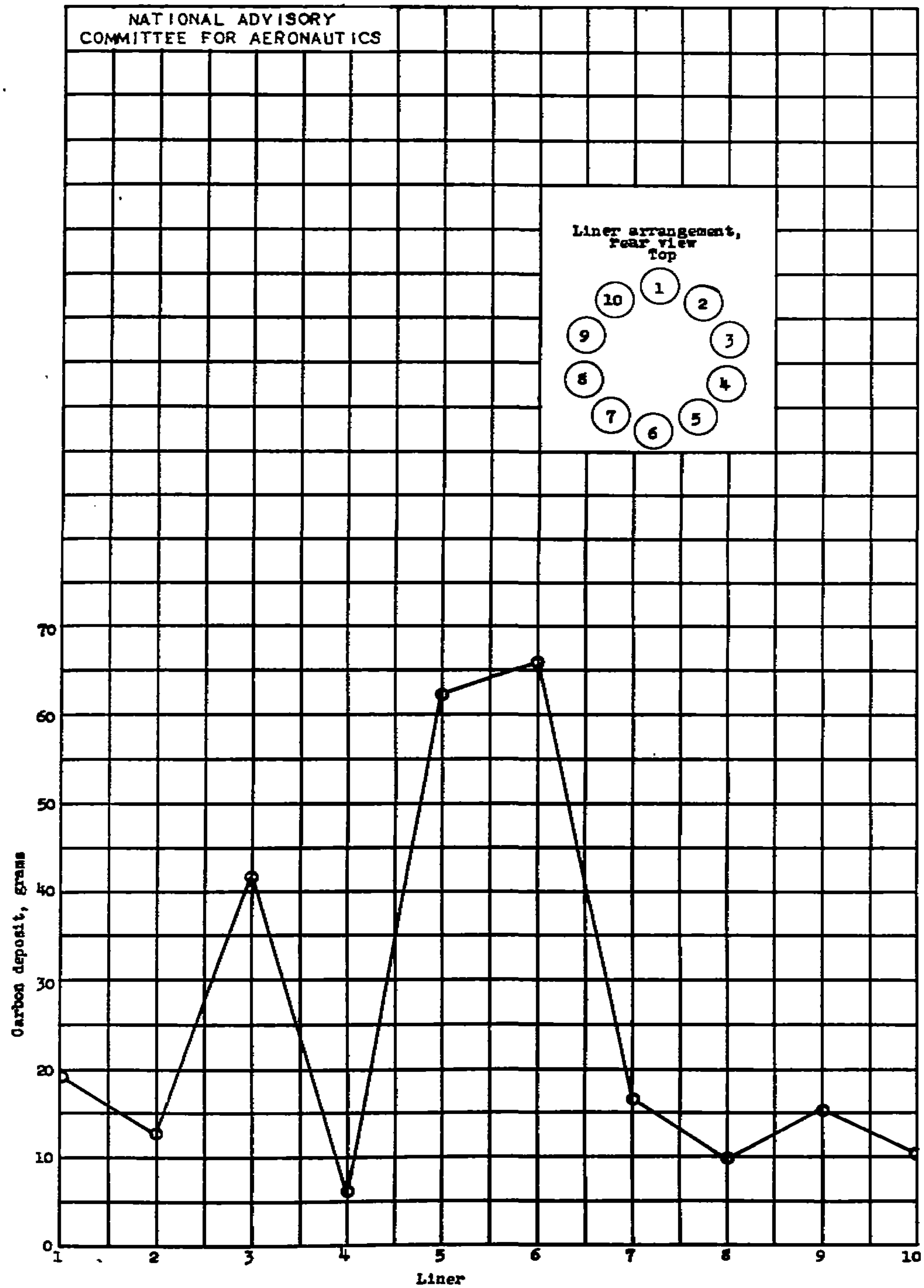



Figure 2. - Distribution of carbon deposits in run using kerosene in I-16 engine with reduced exhaust-jet-nozzle area (run 4). Total deposit, 260 grams.

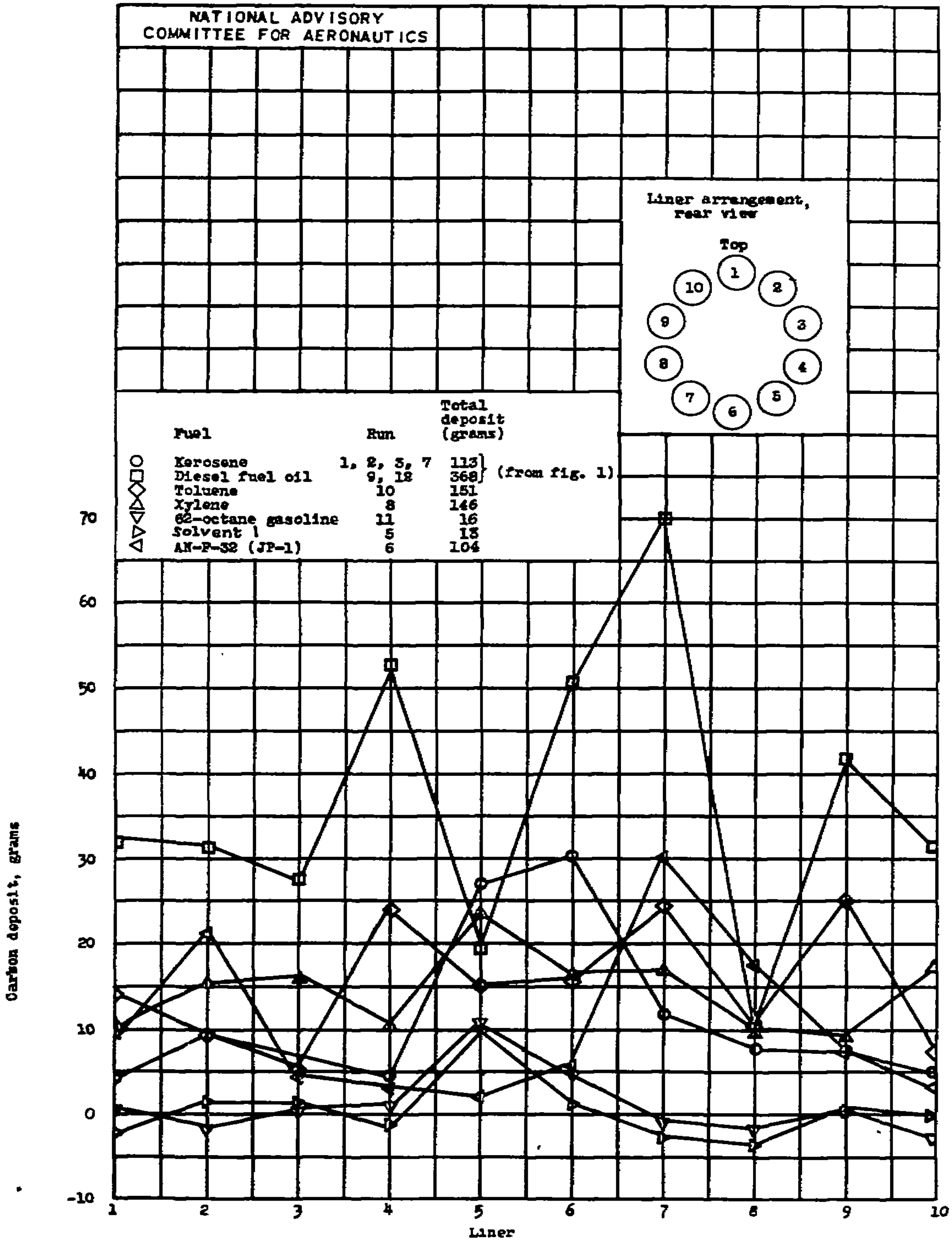



Figure 3. - Distribution of carbon deposits for seven fuels tested in I-16 engine. (Curves shown for kerosene and Diesel fuel oil are averages from the curves shown in figs. 1(a) and 1(b), respectively.)

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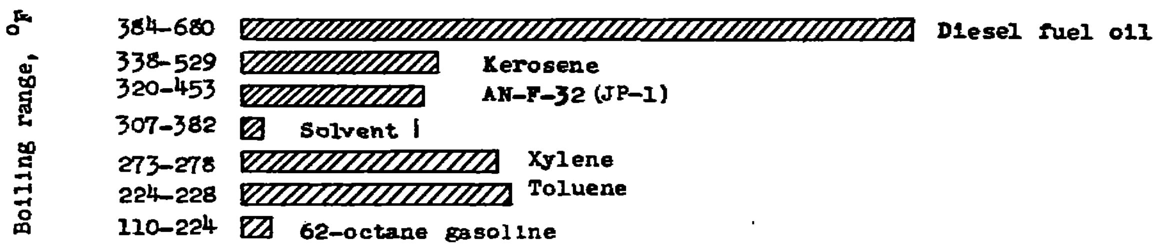
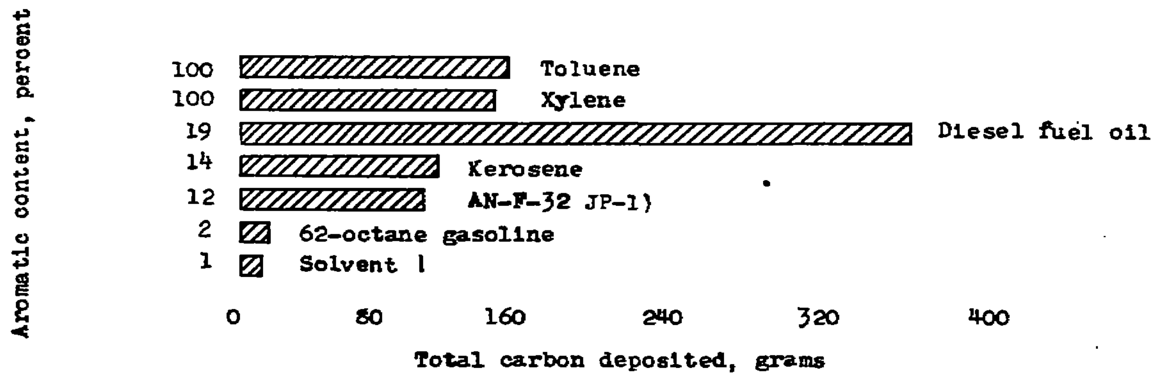



(a) Volatility.




(b) Aromatic content.

Figure 4. - Comparison of total carbon deposited in combustion-chamber liners from I-16 engine with fuel characteristics.


Figure 5. - Combustion-chamber liner 7 from I-16 engine after 2-hour run with Diesel fuel oil (run 12).